Measurement of the $\pi^0 \to e^+e^-$ branching ratio

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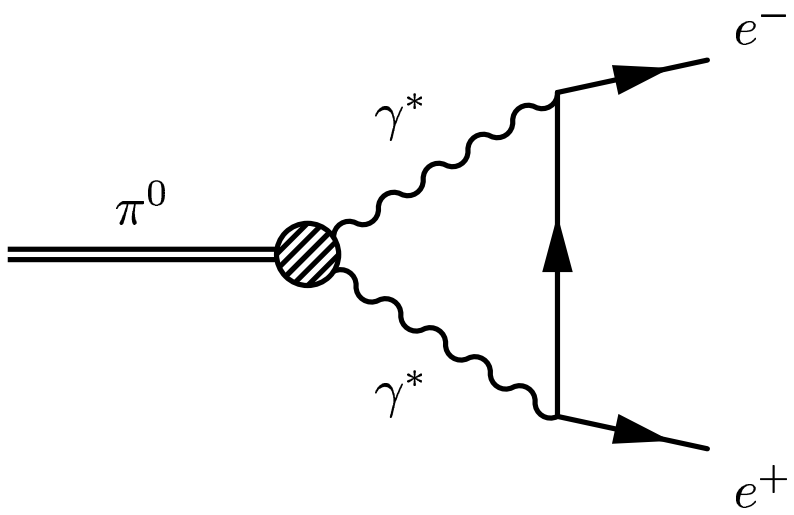
Outline

- Basic structure of the decay $\pi^0 \to e^+e^-$
- Interference with the Dalitz decay ($\pi^0 \to e^+e^-\gamma$)
- The KTeV detector
- The measurement technique
- Signal and background
- Systematic errors
- Preliminary result

The decay $\pi^0 \to e^+e^-$

- $\pi^0 \to e^+e^-$ is a rare electromagnetic decay that proceeds through a loop process at lowest order.
- It is suppressed by two factors of the electromagnetic coupling α and is also helicity suppressed by a factor $(2m_{ee}/m_{\pi^0})^2$.



The decay $\pi^0 \to e^+e^-$

- Assuming a pion form factor the branching ratio to lowest order is (Bergström, 82):

$$\frac{\Gamma(\pi^0 \to e^+e^-)}{\Gamma(\pi^0 \to \gamma\gamma)} = 2\sqrt{1-\left(\frac{2m_e}{m_\pi}\right)}\left(\frac{\alpha}{\pi}\frac{m_e}{m_\pi}\right)^2 |R|^2$$

with

$$R = -\frac{2i}{\pi^2 m_\pi^2}\int d^4k \frac{q^2k^2 - (q\cdot k)^2\ F(k^2,(q-k)^2)}{(k^2+i\epsilon)((q-k)^2+i\epsilon)((k-p)^2-m_e^2+i\epsilon)}$$

- The contribution from on-shell photons comes from the imaginary part of R and sets a lower limit, the **unitary bound**, on the decay rate which is independent of the form factor model:

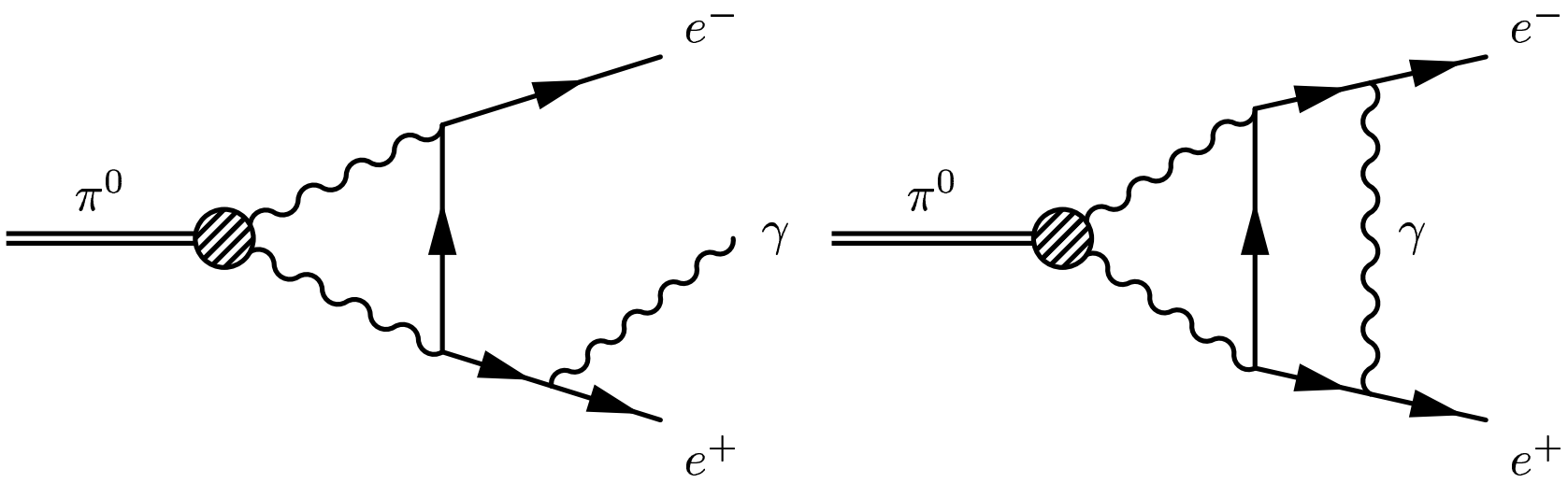
$$\frac{\Gamma(\pi^0 \to e^+e^-)}{\Gamma(\pi^0 \to \gamma\gamma)} \geq 4.75 \times 10^{-8}$$

- Chiral perturbation and meson dominance models for the form factor predict a lowest order rate in the range:

$$\frac{\Gamma(\pi^0 \to e^+e^-)}{\Gamma(\pi^0 \to \gamma\gamma)} = 6 - 9 \times 10^{-8}$$

Next to leading order

- Radiative corrections are introduced in next to leading order treatments. A detailed treatment was done by Bergström(83), calculating both the virtual and the radiative corrections.
- The total correction to the rate from next to leading order terms is -3.4%.

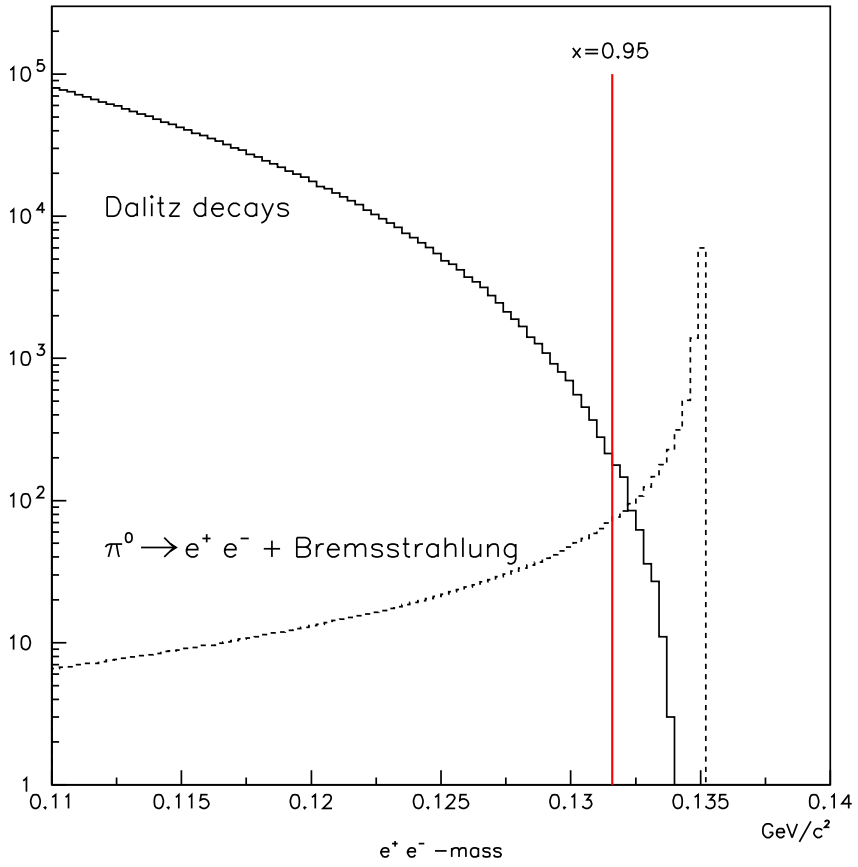


Interference with the Dalitz decay

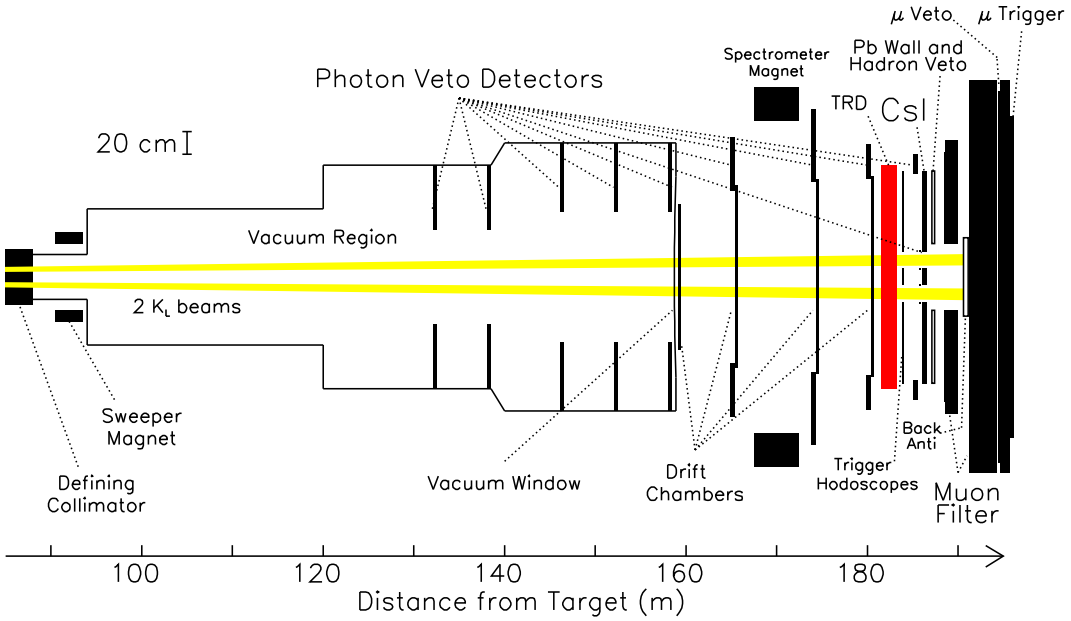
- The $\pi^0 \to e^+e^-$ decay with radiation only distinguishes itself from the much more common Dalitz decay in the region of very soft photons.
- So define branching ratio where there is only soft radiation:

$$\text{BR}(\pi^0 \to e^+e^-,\ x > 0.95), \quad x = \frac{m_{ee}^2}{m_{\pi^0}^2}$$

- The actual quantum mechanical interference between the two modes have been found to be negligible in the high e^+e^- mass region.



The KTeV E799 experiment



- The spectrometer consists of 4 drift chambers and a magnet which measures charged tracks with momentum resolution

$$\sigma(P)/P = 0.38\% \oplus 0.016\% \cdot P$$

- The CsI calorimeter measures electromagnetic cluster energies with resolution

$$\sigma(E)/E = 0.45\% \oplus 2\%/\sqrt{E}$$

and positions with resolution in the millimeter range.

Measurement technique

- We measured:

$$\frac{\mathrm{BR}(\pi^0 \to e^+e^-,\ \ x > 0.95)}{\mathrm{BR}(\pi^0 \to e^+e^-\gamma,\ \ x > 0.232)}$$

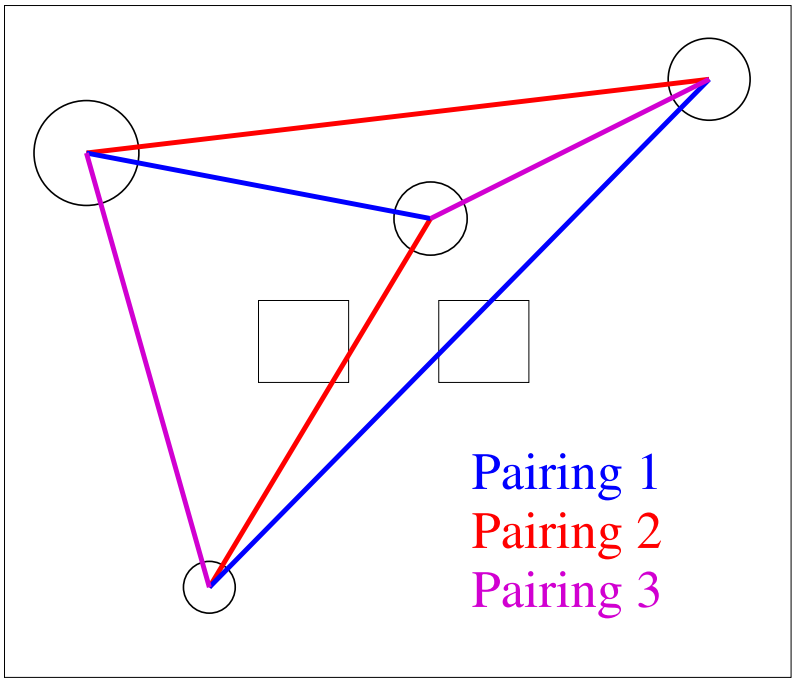
where $x = m_{ee}^2/m_\pi^2$.

- Both modes where extracted by fully reconstructing kaons from the following decay chains:

$$K_L \to \pi^0\pi^0\pi^0 \to \gamma\gamma\ \ \gamma\gamma\ \ e^+e^-$$

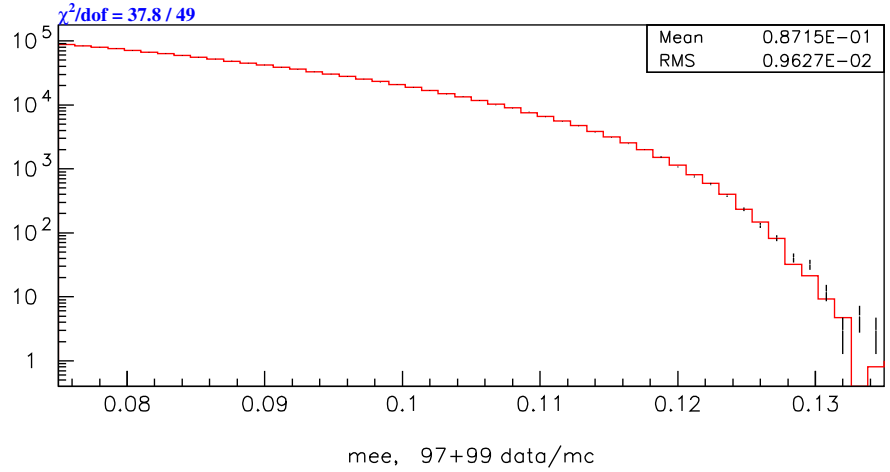
$$K_L \to \pi^0\pi^0\pi^0 \to \gamma\gamma\ \ \gamma\gamma\ \ e^+e^-\gamma$$

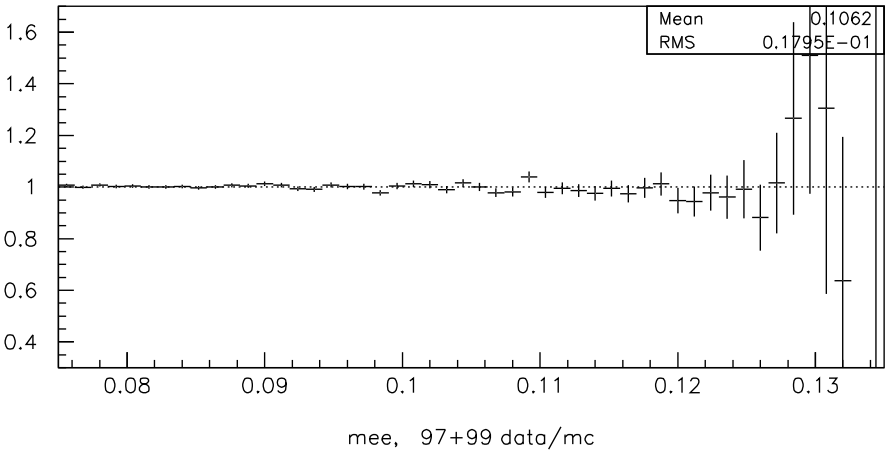
- We required 2 tracks pointing to calorimeter clusters and 4 (5) additional clusters.
- The photon pairing with the best agreeing decay vertex was used.



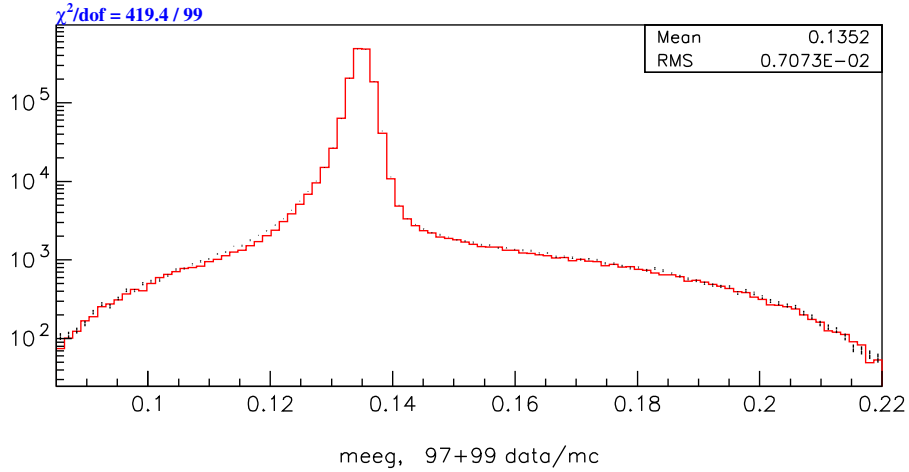
Data-MC comparisons

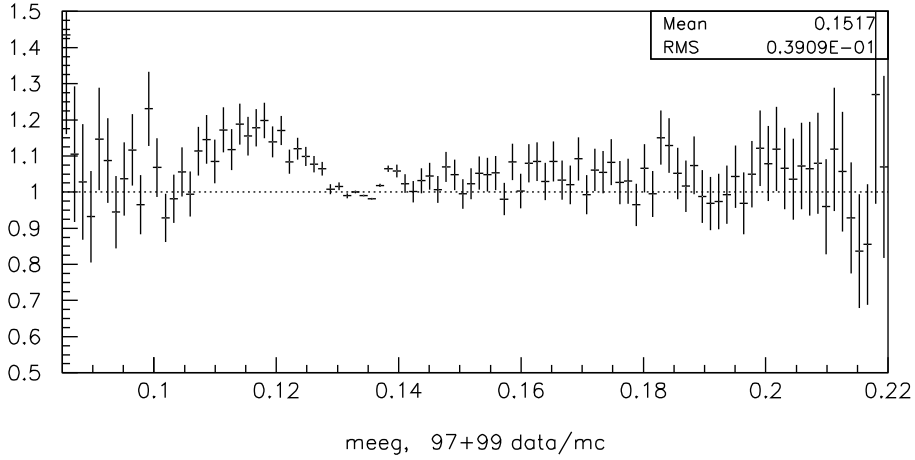
e^+e^- mass





$e^+e^-\gamma$ mass



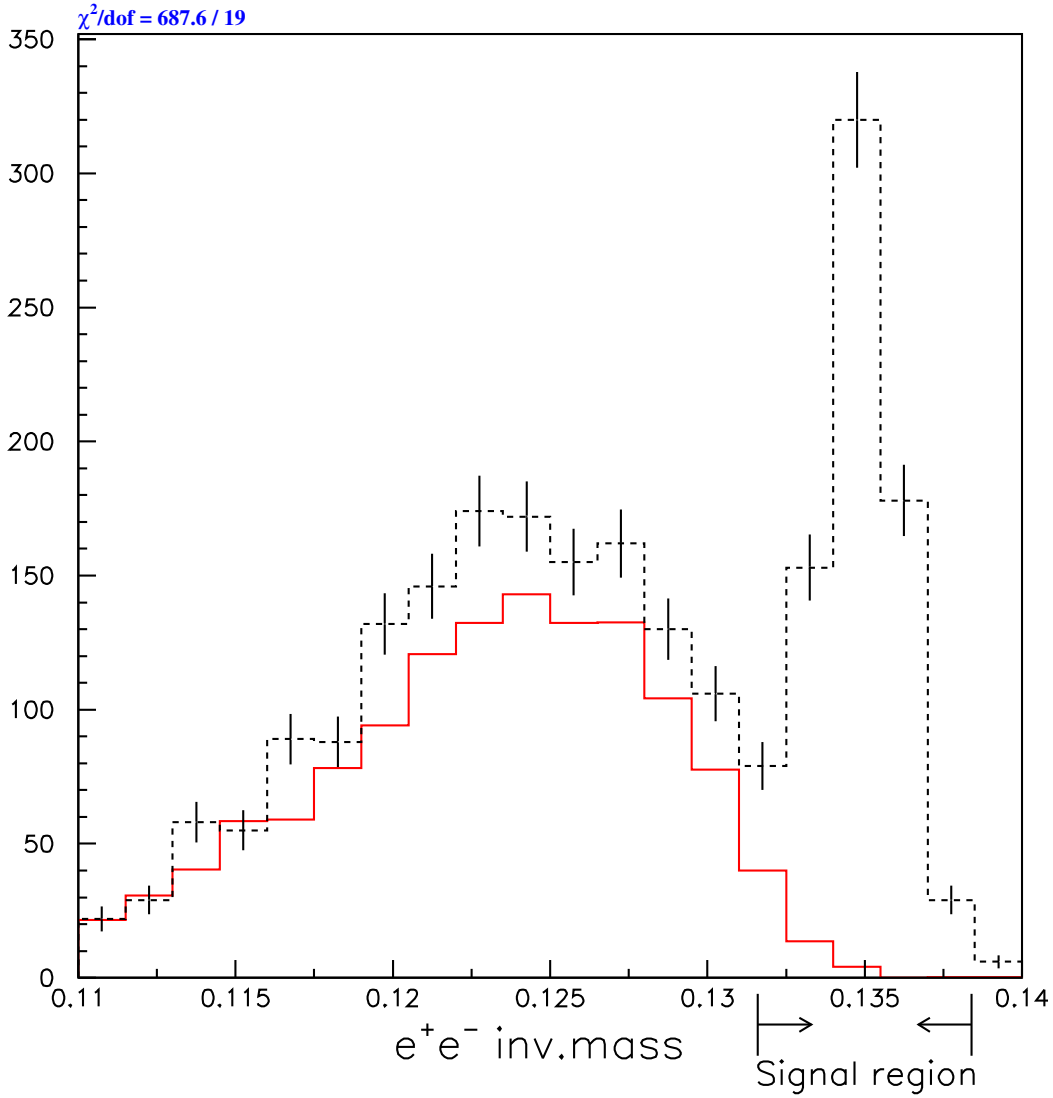


Backgrounds

- Backgrounds to the signal all originated from $K_L \to 3\pi^0$ decays.
  - $K_L \to 3\pi^0 \to \gamma\gamma \quad \gamma\gamma \quad e^+e^-\gamma$
  - $K_L \to 3\pi^0 \to \gamma\gamma \quad \gamma\gamma \quad e^+e^-e^+e^-$
  - $K_L \to 3\pi^0 \to \gamma\gamma \quad e^+e^-\gamma \quad e^+e^-\gamma$
  - $K_L \to 3\pi^0 \to \gamma\gamma \quad \gamma\gamma \quad e^+e^-\gamma$
    with 1 photon converting to an e^+e^- pair.
  - $K_L \to 3\pi^0 \to \gamma\gamma \quad \gamma\gamma \quad \gamma\gamma$
    with 2 photons converting to e^+e^- pairs.

Signal and background

- A comparison of the reconstructed e^+e^--mass for data and background MC is shown.
  Black histogram is data, red line is MC.
- We found 714 events in the signal region with an estimated background of 39.9 ± 12.3 event.
- The statistical uncertainty becomes 4.0%



Systematic errors

- The main systematic uncertainty comes from the background estimate which suffers from a couple issues.
- The main sources are:

Source	Uncertainty associated
Background normalization	1.4%
e^+e^- mass modeling	1.0%
Background MC statistics	0.8%
Photon pairing χ^2 modeling	0.7%
Total Systematic	2.1%

Preliminary branching ratio

- From the 714 signal events and 1,619,561 normalization events we measure:

$$\frac{\text{BR}(\pi^0 \to e^+e^-,\ \ x > 0.95)}{\text{BR}(\pi^0 \to e^+e^-\gamma,\ \ x > 0.232)} = (1.721 \pm 0.068(\text{stat}) \pm 0.036(\text{sys})) \times 10^{-4}$$

  Using the Dalitz branching ratio and the fraction of Dalitz events with $m_{ee} > 65$ MeV the sought branching ratio can be extracted:

$$\text{BR}(\pi^0 \to e^+e^-,\ \ x > 0.95) = (6.56 \pm 0.26(\text{stat}) \pm 0.23(\text{sys})) \times 10^{-8}$$

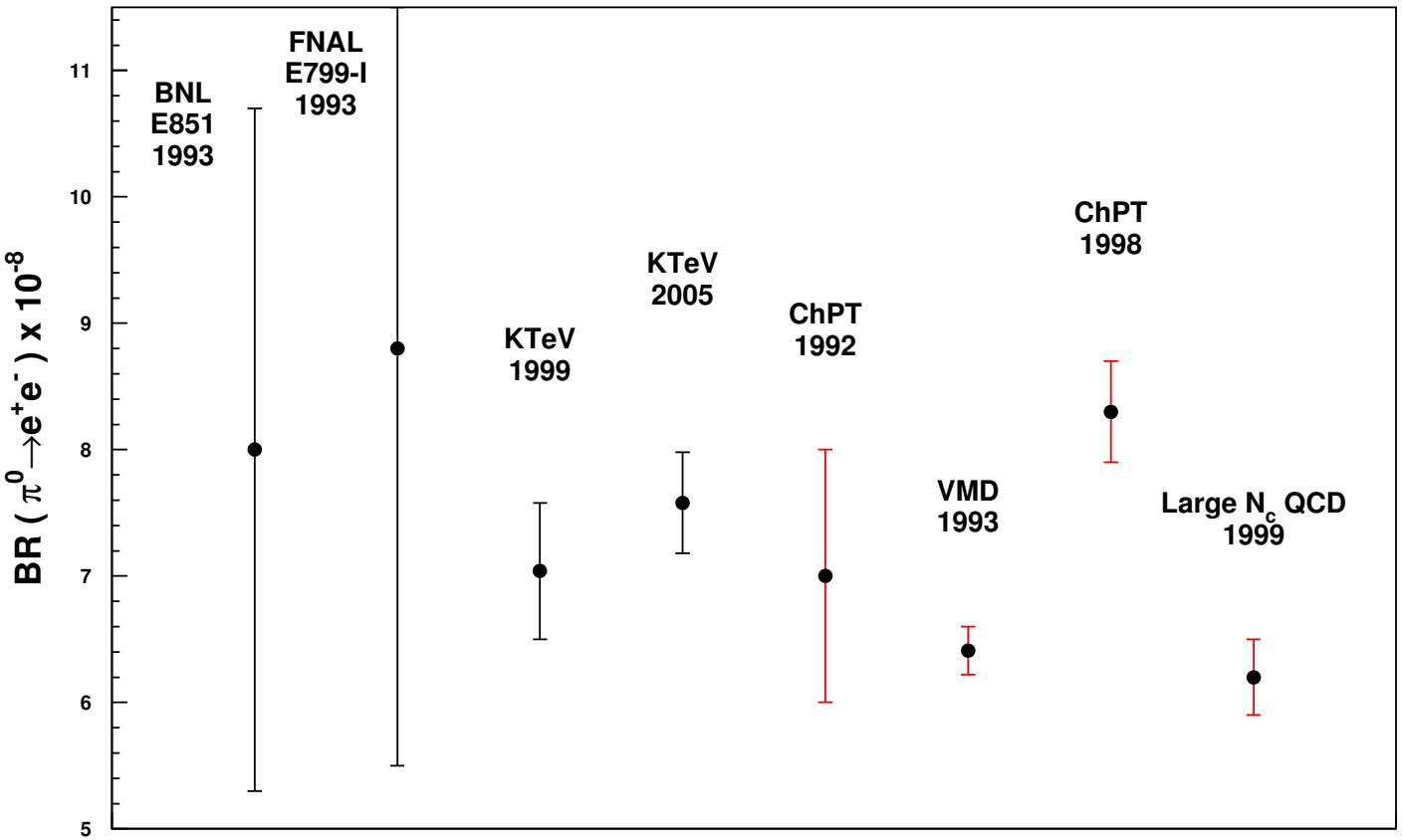
- The systematic error now includes the 2.7% uncertainty in the Dalitz branching ratio and a 0.5% uncertainty from the uncertainty in the π^0 slope parameter.
- The old KTeV result using less than half the data was:

$$\text{BR}(\pi^0 \to e^+e^-,\ \ x > 0.95) = (6.09 \pm 0.40(\text{stat}) \pm 0.24(\text{sys})) \times 10^{-8}$$

Preliminary branching ratio

- The result can be recast in terms of just the lowest order rate which can be used to compare with theoretical predictions:

$$\frac{\Gamma^0_{ee}}{\Gamma_{\gamma\gamma}} = (7.67 \pm 0.30(\text{stat}) \pm 0.27(\text{sys})) \times 10^{-8}$$



BLACK ARE EXPERIMENTS **RED ARE THEORIES**

Conclusion

- A new preliminary result for the branching ratio has been obtained from the complete KTeV E799 dataset:

$$\text{BR}(\pi^0 \to e^+e^-,\ \ x > 0.95) \ = \ (6.56 \pm 0.26(\text{stat}) \pm 0.23(\text{sys})) \times 10^{-8}$$

- The new result has a statistical uncertainty of 4.0% and a systematic uncertainty of 3.4%.
- In its final version it will supersede the old 1999 KTeV result.